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USING ELECTROFACIESSES IN OIL RESERVOIR STUDIES

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Abstract: *Reservoirs and petroliferous structures characterization include not only defining the petrophysical rocks properties but also formations structural and sedimentary features. Electrofacies seen as a geophysical parameters response to the geological facies allows this correlation and structural analysis. Using adequate methods are depicted the main formation characteristics such as lithology, mineralogical composition, deposits structure and texture, fluids content and sedimentary sequences. Summing the logs values for a certain depth or interval, comparing their shape and specific configurations emphasize the structural and sedimentary features. This permits us to make an analysis regarding stratigraphic, sedimentary and tectonic (sometime) evolution of the researched area. Different electrofacies models allow also a more realistic correlation of the geological markers from one well to another and, extrapolating to the structure or accumulation zone surface. In the last time, the electrofacies studies are used to characterize the mature reservoirs too, obtaining from them the residual reserves areas.*
Keywords: *electrofacies, shape, interpretation, mineral composition, logging, well*

1. Introduction

Interpreting the stratigraphy, lithology, sedimentary sequences and fluids of subsurface units has historically depended, in large part, on rock samples, the relative correct identification reliable data being based on core samples. However, cores may be prohibitively expensive or difficult to access. In addition, it is impossible to obtain a continuous coring interval at a well length. In the same time wireline logs, or lately MWD logs can be obtained for the entire interval of interest under varied environmental conditions and at detail. One approach integrating log-derived information on stratigraphy, lithology, and hydrogeology in a single study is through electrofacies analysis [1].

The electrofacies gathering depends closely on the variables (logs) in use. The electrofacies definition and prediction normally combines a statistical analysis with the standard geological interpretation of logs. Logs and core data are both considered to generate facies logs that honor both pieces of information. The Situation described above requires an important number of logs recorded in all or many wells drilled on a geological structure. Also it can be extended to seismic data to obtain better areal distributions. Only a few, mainly newly discovered structures have this high density of values from different well logs so in structures discovered sustain our determination on less, old data recorded, many of them teens years ago.

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2. (Electro) Facies definition and properties

In a large accepting manner the "facies" represents a certain domain of existence of one system defining parameters (factors), and in a real manner, for sedimentary formations facies represents the sum of essential characteristics of the depositional environment where was generated a sedimentary formation (Signaux 1936). Now these environmental characteristics are reflected by the sum of petrographic characteristics of a sedimentary formation in a certain point (lithofacies) and its paleontological content (biofacies). The set of well logs at any level in the borehole can be considered as a description of geological formation(s), on the considered interval, by the terms of geophysical parameters recorded as: resistivity, density, hydrogen index, spontaneous potential, acoustic waves transit time, natural radioactivity etc. More each log method answers and respectively its shape on the diagraphy is a function of many rocks physical properties. Each recorded curve is a unique answer to a larger or narrower domain of formation properties. So a resistivity log diagraphy is the answer to formation fluid type, porosity, cementing degree, tortuosity and clay content, as well as a neutronic log value is related with formation hydrogen content, thus its porosity [2].

2.1. Adequate methods

By processing complete well logs can be done a global image of formations characteristics making geophysical parameters values correspondence to geological facies (table 1).

Table 1. Well logs response relevance in formation characterization (after Serra and Abbot, 1980)

Log type (measured parameter)	**Symbol**	**Comparative importance of geological parameters**			
		Mineralogical composition	**Texture**	**Structure**	**Fluids content**
Resistivity	ρ	X	XXXX	XXX	XXXX
Spontaneous	PS	XX	XXX	XXX	XXXX
Electromagnetic waves Propagation time	τ	XX	XXX	XXX	XXXX
Electromagnetic waves	A	XX	X	X	XXXX
Natural Gama Radiation intensity	I_{γ}	XXXX	X	X	X
Natural spectral Gama radiation	$I_{\gamma s}$	XXX	X	X	X
Hydrogen index	IHM	X	XXX	X	XXXX
Density	δ	XXXX	XXX	X	XXXX
Photoelectrical Capture section	Pe	XXXX	X	X	X
Thermal neutrons Capture section	∑	XXXX	X	X	X
Elastic waves travel time	Δt	XX	XXXX	X	XX
Elastic waves	A	XX	XXX	XXX	XXXX
Inelastic Gama Spectrometry	-	XXXX	XXX	X	XXXX
Dip meter	-	XX	XXXX	XXXX	X
Caliper	-	XXX	XXXX	X	X
Thermometry	°C	XXXX	X	X	XXXX

We may establish a series of correlations between the principal domains of facies such as mineralogical composition, rocks texture geological/structural arrangement and fluids content, and their answer on log diagraphies (Serra1980). Also each method has a better or lesser relevance to a certain characteristic.

These are presented on the table above (table 1). Because the parameter measured value is a sum of all rocks characteristics, with different influence (weight) in the final value, the more log types were recorded, the better characterization will be.

Mineralogical composition of a sedimentary rock type is generally limited to the simultaneous presence of some dominant minerals, using an adequate investigation methods set (well logs), specific for lithology and porosity, we may accomplish a quantitative determination of the mineralogical species amount [3].

Adequate methods for this evaluation are compensated neutronic log, borehole compensated acoustic log, lithodensity log and natural Gama ray logs (total and spectral). Also their computed interpretation provides reliable lithology/porosity determinations.

Rocks' texture is characterized by grins dimensions, sorting and distribution, matrix type, cement type and others. It is linked with the porosity, permeability and tortuosity values of the rock (figure 1).

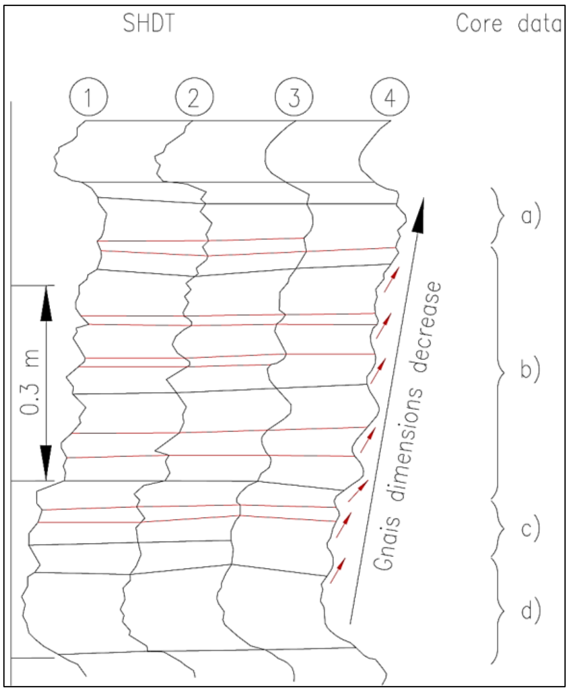

Fig. 1. Sedimentary sequence emphasize on well log diagraphy

There is a direct correlation between rock's texture and its image on the well logs diagraphies [4]. So grains dimensions variation is emphasized by a gradient (dipping) disposition of the measured values in the next figure is presented with the resistivity values from a dip meter log (SHDT type) representing a variation from medium sand grains to fine marls (figure 2).

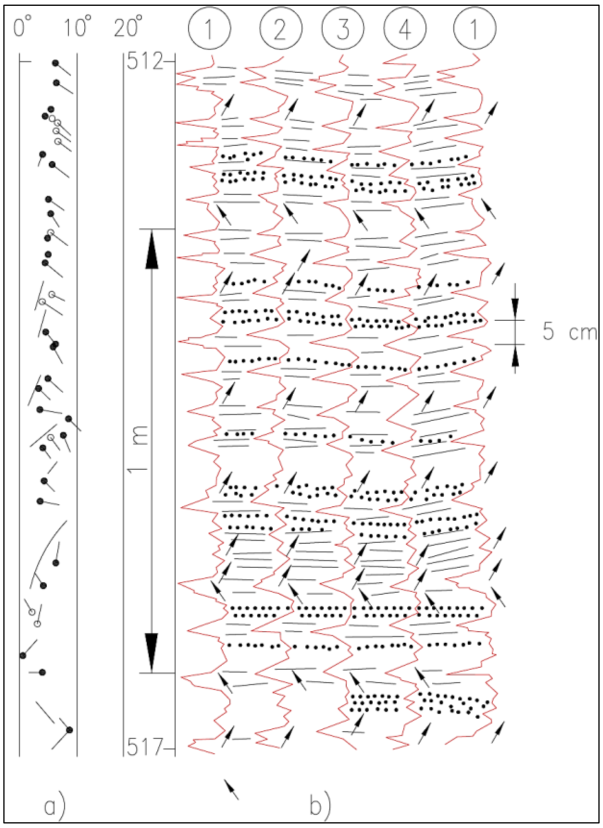

Fig. 2. Complex representation of dip meter data processing:
a) layers dip and azimuth; b) sedimentary sequences

Continuous lines represent characteristic correlation points and interruptions represent the variations induced in in the diagraphy by the existence of clay laminations into the sedimentary sequence. Such models can be observed also on other types of diagraphies as resistivity, Gama ray and synergetic representations. Sedimentary unit structure is characterized by its geometrical elements, thickness, lamination etc.

Large-scale recorded logs from dip meter log types such as SHDT, CMI, etc. emphasize the structural details because the vertical resolution is very high. For this reason on the diagraphies we may determine the layers structural and depositional dip, clay laminations, their thickness stratification dip and others [5]. In the next (figure 2) is represented this type of interpretation for a succession of sands and thin laminated clay.

Fluids content influences mainly the resistivity values and thus electric logs diagraphies shape. As a quick interpretation we may appeal to the position of different geology-geophysical markers on the correlating logs.

2.2. Correlating electrofacies with geological facies

It is obvious that at this moment there exist many computed electrofacies correlations but sometimes it is better to have some geological spikes, markers, initial determined to calibrate the well logs interpretation. Having a method of electrofacies determination on a given interval (formation) the main problem consists of correlating the geological facies with electrofacies.

When we have mechanical cores, the problem is easier because it is possible to compare and correct the well logs data with the rocks samples. Even so sometimes to a single geological facies are corresponding more electrofacies due, as an example to the salt content of the formation fluids which induces high resistivity values variations.

2.3. Electrofacies determination phases

According to the vertical resolution of the different well log types of the recorded values correspond to a different vertical interval between 0.25 and 0.5 cm. Each logs set can be represented as a data matrix with a certain depth recording step. This matrix can be considered as consisting of a multitude of n – dimension vectors each of them representing formation response to a well logging method. Mathematically we define it as a cluster for depth (i) values.

$$[x] = [^{log\ 1} x_{ij}]^{log\ p} \tag{1}$$

where:
$x_{ij} = log_j$ measured at point i.

So we may divide the investigated interval in electrofacies intervals depending on “n” – dimension vectors mentioned above, these values can be separated in classes or groups, thus tend to be placed nearby the characteristic values forming data “clouds”.

For a correct electrofacies determination it is necessary that the existing diagraphies to be corrected for depth, borehole influence, etc. and the obtained data to be zoned. Zoning the recorded values refers to the selection of a defined as an adjacent depth level for which the diagraph presents constant or very close values (inessential differences) (figure 3).

The recorded parameter variation may have many causes such as:
- real variations of formation properties,
- logging errors due to borehole conditions (as important excavations),
- recording process errors.

Values zoning can be done visual or automatically the resulting diagraph being composed of depths segments (intervals) having constant values of the measured parameter [6].

This induces a reduction of the “data clouds” and of the matrix of n-dimensional vectors emphasizing distinct values for distinct electrofacies. This reduction can be observed in diagraphs frequency histograms on distinct intervals in a well profile (figure 3).

3. Electrofacies identification

Onsetting the geophysical diagraph interpretation to study the formation sedimentary features implies the examination of its shape for establishing the necessary indications regarding rock types and sedimentary environment. In the next figure is presented one or the most used classifications used for this purpose (figure 4), (Serra and Abbot Classification) [7].

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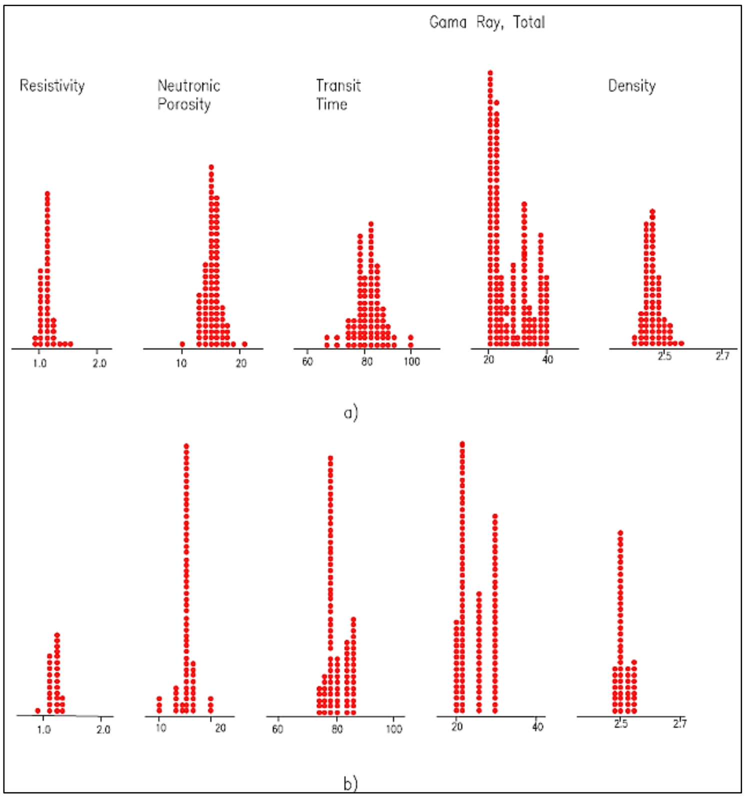

Fig. 3. Diagraphs values zoning: (a) raw data; (b) zoned data

Therefore, we may distinguish electracies with different shapes:
- cylindrical sharp limits smooth –a, or indented – b, curve,
- gradual change: bell shape, funnel shape and barrel shape, smooth or indented curve, with concave – α; linear – β or convex – γ configuration.

Different sedimentary environments are reflected by one of these configurations as (Kolovos 1988):
1. Dejective cones reflected by a monotone curve generated by coarse channel sands,
2. Braided channels may have a bell shape due to a finning up sequence but sometimes this variation is not significant so they will have a cylindrical shape.
3. Meandered channels have generally a bell shape according to the sharp change sand/clay on channel floor and fining upward upper reservoirs.
4. Aeolian dunes are usually bell shaped turning to bell shape towards layers top due to the fining up sequences, sometimes they present laminate clay (thin) intervals which provide an indented curve shape.
5. Sands banks at the distributaries channels mouth with a coarsening up profile provide a funnel shape electrofacies, sometimes it is observed a sudden change at the upper part from clean well sorted sands to coarser sediments of the roof.
6. Coast barrier islands have usually a smooth funnel shape related to an increase in the grains size, sorting and permeability.
7. Coast continental shelf sands may have different shapes, funnels due to coarsening up sequence, indented cylinder and rarely bell shape.
8. Deep sands are reflected by cylindrical or bell shape, with specific supplying channels,

Similar correlations can be established for other types of well logs diagraphs such as Gama ray, neutronic porosity, or clay content. Synergetic logs representations may also assure very good results.

The main types of electrofacies are:
- Barrel (B).
- Funnel (P).
- Bell (C).

The following can be drawn from the (table 1):
- Structural map.
- Map with isopaches’.
- Lithofacies map: – resistivities.
  – electrofacies.

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Electrofacies of different shapes can be distinguished (figures 4):
- with a steep transition, having the shape of a cylinder (1) which can be smooth (a) or indented (b).
- with a progressive passage in the form of a bell (2), a funnel (3) or a barrel (4), each of which can be smooth (a) or indented (b) and having a concave (a), linear or convex configuration.

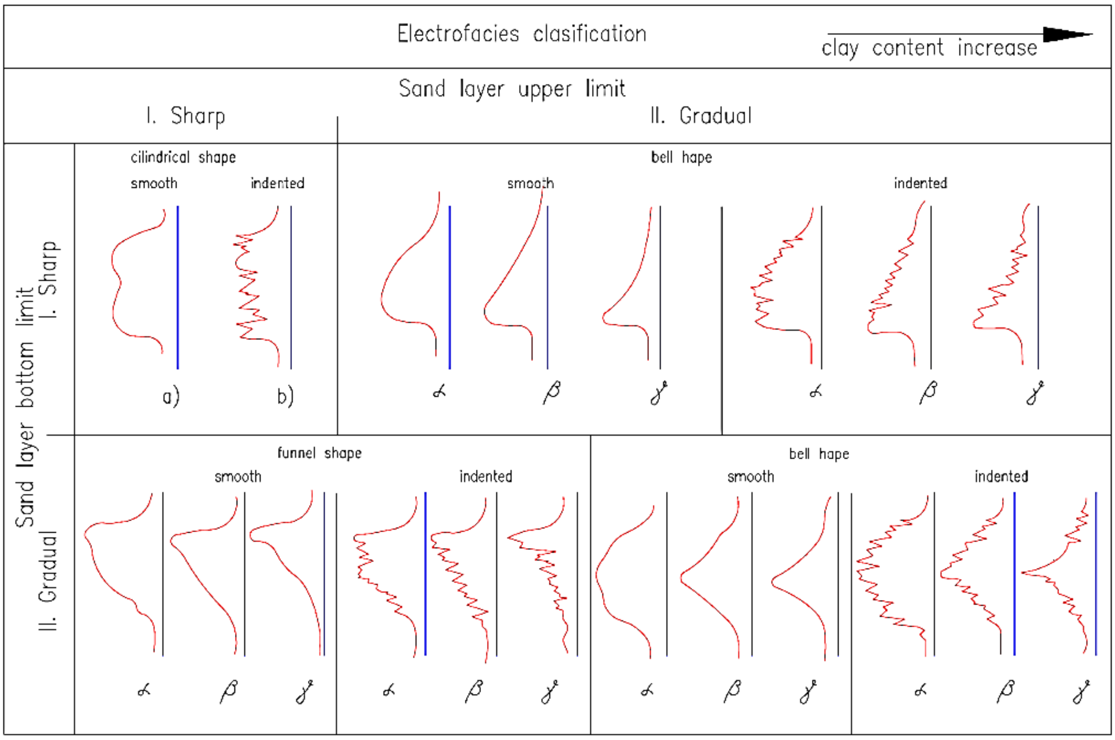

Fig. 4. Electrofacies types from lithological curve - SP, (after Serra 1986, modified)

According to Kolovos 1988, the various sedimentation environments are reflected in one of these configurations:
- dejection cones, reflected by a monotonous curve being generated by coarse channel sands.
- the unbraided channels can sometimes have a bell shape, due to portions of coarser sand that becomes fine upwards, but often this variation is too small to produce a well-defined profile, in this case cylindrical shapes are encountered.
- channels produced by the meandering, courses reflected by abrupt changes from sands to clays at the base of the channel and gradual changes at the top giving a bell profile.
- the aeolian dunes are reflected by an appearance in cylindrical shapes to bell shapes that become fine upwards, possessing a steep base; often presents lamination of clayey rocks, giving an indented appearance.
- the sandbanks at the mouth of the distribution channels, Spontaneous Potential curve shows a profile that becomes coarser upwards (in the form of a funnel), in the upper part a sudden change can be observed indicating the transition from well-sorted clean sand belonging to the upper bank to a roof of granular sediments.
- coastal barrier islands. P.S. curve usually shows smooth funnel shapes, reflecting increased granulation, sorting, and increased permeability upward; larger amounts of fine material flatten the curve while clean sands will generate cylindrical profiles.
- the sandbanks at the mouth of the distribution channels. Spontaneous Potential curve shows a profile that becomes coarser upwards, in the form of a funnel, in the upper part a sudden change can be observed indicating the transition from well-sorted clean sand belonging to the upper bank to a roof of granulated sediments.
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- continental shelf sands can have different shapes of the Spontaneous Potential curve. Funnel due to coarse sedimentation towards the top, indented cylinder and rarely bell.
- the deep sands are reflected by a curve of Spontaneous Potential typically cylindrical or bell-shaped, representing characteristic feeding channels. Similar correlations can be established for other types of diagraphs such as natural radioactivity, neutron porosity or clay content from the combination – Density logging – Neutronic logging (Gama Rays).

For the identification and evaluation of electrofacies, the so-called “spider web” or "ladder" graphs are also used, where each axis has the scaled values of a geophysical diagram from the set of investigations performed (figure 5) [8].

In the same manner can be used the so called “areal” electrofacies types among them scale and spider net graphs having good results mainly to identify facial markers (figure 5) [9].

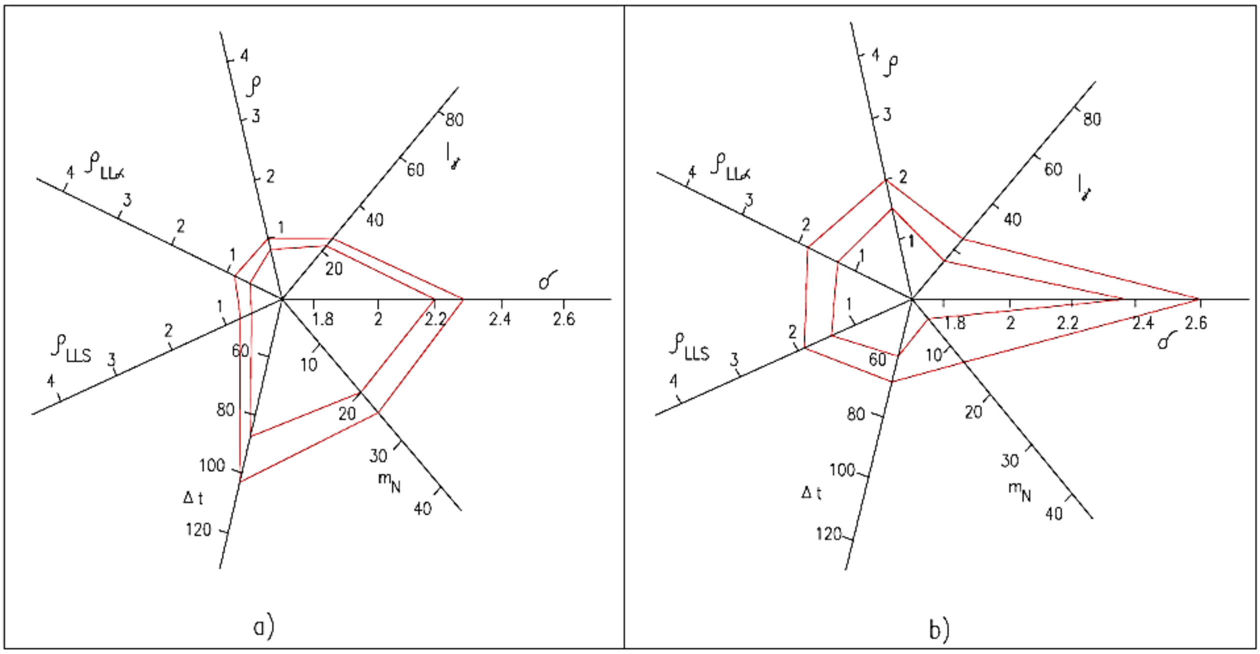

Fig. 5. Spider net electrofacies representation: (a) sandstone; (b) limestone

They consist of graphical representation on a fitted scale of more logs values for a certain depth or, better for the zoned values of the parameters on a distinct interval. These representations are very suggestive for emphasizing the different rock types and sedimentary units.

The values are plotted on parallel or radial scales and by unifying the parameters values for a depth or zone we obtain a unique shape for the respective facies. It is enough that they only have one parameter to have distinct values to identify a new facies. In the figure below are presented these identification possibilities for a spider net electrofacies representation.

Obviously, now, electrofacies evaluations are obtained easily with dedicated computing methods, software but for a better understanding it is necessary to emphasize the roots of these evaluations and, in some situations, to define and implement markers in the computing process.

3.1. Electrofacies concept applications

The electrofacies represents, essentially, the reflected image, on the well logs diagraphs, of analyzed formation characteristics allowing so its description. The main domains where it is used are:
- Electrofacies identification and establishing correspondent geological facies.
- Recognizing and analyzing the depositional sequences.
- Stratigraphical markers identification.
- Correlation of electrofacieses from different wells.
- Construct electrofacies maps.
- Sedimentological, eventually paleo geographical analysis.
- Automatic interpretation of logs data as a function of the determinate model.
- Forming data banks with facieses on reservoirs, oil structures, accumulation zones, sedimentary basins.

Used in a proper manner the information provided by the electrofacieses types we may achieve a general improvement of sedimentary models identification and interpretation and emphasizing the characteristic elements of hydrocarbon accumulations.

Referring to the mature oilfields the electrofacieses' studies allows emphasizing of the lithofacies variations both, on vertical scale-in the wells, and, by extrapolating, to the reservoir surface. By recognizing the lithofacies model we shall have a more exact image of the reservoir and oilfield properties [10].

3.2. Case study (Complex interpretation)

Based on the data from a deposit, a complex interpretation was made both from the point of view of separating the complexes (head and base) and from the point of view of identifying each complex based on the type of electrofacies.

Case study (well 5) identification of the electrofacies according to the curve of S.P. (the left side of the diagram) and resistivities (the right side of the diagram), according to figure 6.

- Total thickness – 20 m
- S.P. log – electrofacies – bell shape indented
- Resistivity logs – electrofacies – funnel shape indented

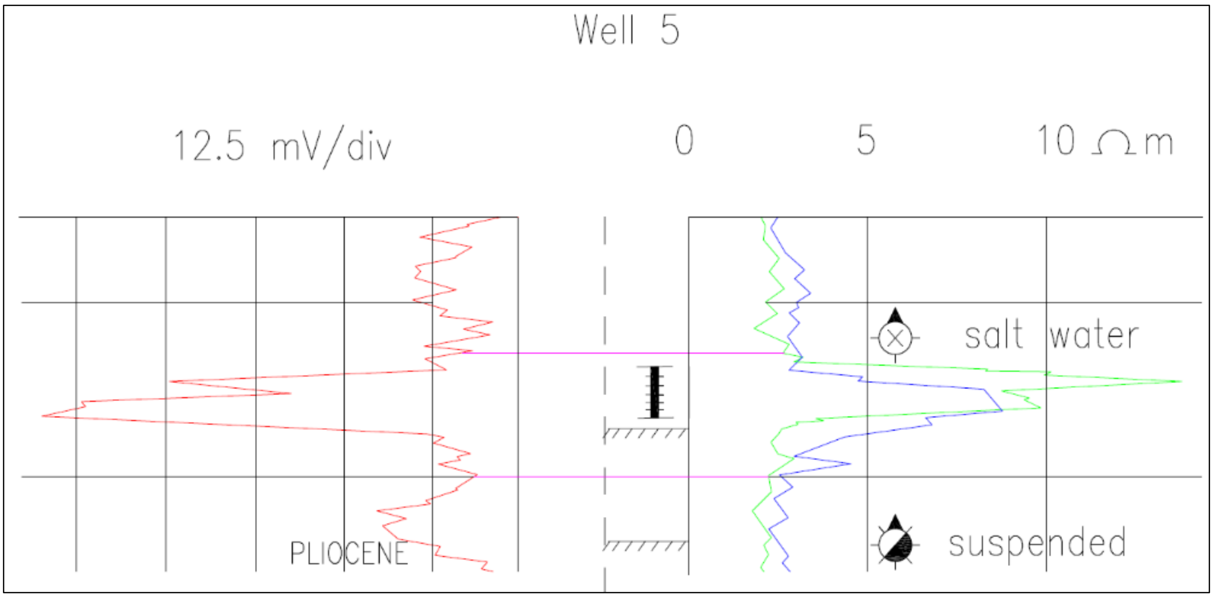

Fig.6. Electric logging well (SP. – Potential Spontaneous)

4. Conclusions

Electrofacies can be defined as a geophysical parameters reason for the formation of geological features (stratigraphical, sedimentary, structural).

On a mathematical approach, it is a matrix of the logs values, as n – dimension vectors for a certain depth and/or interval.

Using the adequate logging method is emphasized better the required parameters but for a correct understanding and geological facies evaluation is optimum to have as many logs as we can run into the well and if possible, on its entire length.

For detailed studies, sedimentary sequences analysis must be used methods with high vertical resolution such as SHDT or similar others.

Even from the shape of a single lithological curve shape, such as SP or GR, we may emphasize distinct features such as sedimentary sequences, depositional environment and reservoir variations.

Using refined methods such as spider net electrofacies can be selected a certain rock/sequence type and its existence domain. These allows a better vertical or even horizontal correlation and can be used as markers for shifting the automatic electrofacies evaluations by dedicated programs. Obviously, computed electrofacies evaluations are easier and very fast but shifting them with refined markers from rock samples and/or electrofacies manual sharp determinations will improve their quality.

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